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Calculated Yields From Young-Growth Ponderosa Pine Management

by Orlo W. Krauter, woodland conservationist,
and Vernon W. Baker, agricultural economist,
Soil Conservation Service

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This publication presents a method for calculating future yields from management of young second-growth ponderosa pine. Certain assumptions necessarily have been made, based on the best technical information available. These serve as a basis for calculated step-by-step procedures for thinning young stands, using basal area as the control factor. These procedures determine, for a given rate of growth, the spacing requirements of trees in the stand to obtain maximum usable production. Potential yield tables have been calculated, assuming different levels of increased growth. This information will help guide foresters and woodland owners in establishing management programs.

Economic guides based on these yield tables have been developed in a second publication (1).

CALCULATED YIELDS FROM YOUNG-GROWTH PONDEROSA PINE MANAGEMENT

by Orlo W. Krauter, woodland conservationist, and Vernon W. Baker,[1] agricultural economist, Soil Conservation Service

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Future supplies of wood products will depend more on the management of second-growth stands. Farm woodlands, comprising a third of the Nation's total woodland, are primarily second-growth stands. Many of these woodlands are subject to competing land uses. It is only by knowing their productive capacity and net income potential that an intelligent decision on their use can be made. The Soil Conservation Service has responsibility for guiding landowners in the productive use of their farmlands to conserve both land and human resources. It is with this in mind that attention is directed to woodland production as a farm crop.

An attempt is made here to develop criteria and a method for predicting future production from managed stands. A second report deals with the development of economic guides to management based on the production schedules presented here (1).[2]

Production Potential of Managed Stands Unknown

Research or management experience in ponderosa pine has not been conducted for a long enough period to determine the production that can be obtained from well-managed stands. This should not preclude making logical assumptions and on such basis establishing criteria and guides for growing bigger and better wood crops by which management can proceed objectively. Years of research may be required before conclusive data are available. It seems certain that management needs in the near future will greatly outdistance research results.

The assumptions made here are based on the best information and judgment available. As research reveals better information, substitution can easily be made in the criteria and guides. The method and analysis set forth here will help pinpoint needed research and it is hoped will hasten the time when data will be available to replace the assumptions.

How Normal Unmanaged Stands Grow

Table 1 summarizes growth of ponderosa pine per acre in natural fully stocked stands of site indexes 60, 80, and 100 (6).[3] Nature's method of regulating and managing forests is revealed in these growth figures. An acre of woodland fully stocked starts out with many more trees than can be grown to maturity. Trees compete with each other for light, moisture, and plant nutrients. In the struggle for existence some trees gain dominance. Others die early; still others are gradually suppressed and eventually die.

Thus, for dominant or more aggressive trees to grow, "room" is made available for them by natural thinning. This mortality may come from accidental causes as well as from competition within the stand.

Table 2 shows for normal ponderosa pine stands on site index 80, periodic mortality in number of trees, growth of stand in average diameter and height, and basal-area increments.

According to Meyers (6) at about 50 to 55 years of age a normal ponderosa pine stand

[1] Acknowledgment is made of the assistance given by Paul E. Lemmon and Clyde Deardorff, Soil Scientists (Forestry), and the Western States Woodland Conservationists of the Soil Conservation Service, U. S. Department of Agriculture.

Comments and suggestions obtained in review of the manuscript from the Pacific Northwest Forest and Range Experiment Station and the Boise Research Center, Intermountain Forest and Range Experiment Station, Forest Service, are appreciated.

[2] Figures in parentheses refer to Literature Cited page 14.

[3] Site index for ponderosa pine is measured by height at a specified age. In this publication, site index is the height attained by the average dominant tree at 100 years of age.

TOP, An overstocked stand of 30-year-old ponderosa pine on site indexes 70 to 80. This is typical of stands in northern Idaho and eastern Washington. The rate of diameter growth of these trees is slow, due to the extreme competition for moisture, light, and plant nutrients. BOTTOM, The same stand precommercially thinned, allowing sufficient space for rapid tree growth. The wide spacing provides "growing room" until commercial products can be obtained from future thinnings.

TABLE 1.--Growth factors per acre of normal unmanaged stands of ponderosa pine[1]

Age (years)	Site index 60				Site index 80				Site index 100			
	Trees	Average diameter	Average height (2)	Basal area	Trees	Average diameter	Average height (2)	Basal area	Trees	Average diameter	Average height (2)	Basal area
	Number	*Inches*	*Feet*	*Square feet*	*Number*	*Inches*	*Feet*	*Square feet*	*Number*	*Inches*	*Feet*	*Square feet*
20.....	4,600	1.3	12	46	2,250	2.4	20	70	1,280	3.6	30	93
30.....	3,678	2.3	20	106	1,750	3.8	32	138	1,000	5.5	44	165
40.....	2,700	3.2	28	151	1,270	5.1	42	180	785	7.0	55	210
50.....	1,732	4.2	35	167	905	6.3	51	196	574	8.5	65	226
60.....	1,145	5.1	42	169	662	7.4	58	198	445	9.7	73	228
70.....	831	6.0	47	169	502	8.5	64	198	352	10.9	80	228
80.....	634	7.0	52	169	393	9.6	70	198	286	12.1	88	228
90.....	495	7.9	57	169	316	10.7	75	198	236	13.3	94	228
100.....	400	8.8	60	169	266	11.7	80	198	199	14.5	100	228
110.....	329	9.7	63	169	225	12.7	84	198	172	15.6	106	228
120.....	281	10.5	66	169	196	13.6	88	198	152	16.6	111	228

[1] Data taken from tables 1, 3, 4, and 5 in U. S. Dept. Agr. Tech. Bul. 630.
[2] Dominants and co-dominants.

reaches its maximum basal area.[4] Thereafter, basal area becomes the space indicator for continued growth; i.e., if diameter growth of individual trees increases, there must be fewer stems per acre. Thus the process of mortality continues.

TABLE 2.--Changes per acre in growth factors of normal unmanaged stands of ponderosa pine, site index 80[1]

Age class (years)	Loss of trees	Periodic increment		
		Height	Diameter	Basal area
	Number	*Feet*	*Inches*	*Square feet*
20-30.....	500	12	1.4	68
30-40.....	480	10	1.3	42
40-50.....	365	9	1.2	16
50-60.....	243	7	1.1	2
60-70.....	160	6	1.1	0
70-80.....	109	6	1.1	0
80-90.....	77	5	1.1	0
90-100.....	50	5	1.0	0
100-110....	41	4	1.0	0
110-120....	29	4	.9	0
120-130....	23	4	.9	0
130-140....	20	4	.9	0
140-150....	15	3	.8	0
150-160....	12	3	.8	0
160-170....	11	3	.8	0
170-180....	9	3	.7	0
180-190....	7	2	.7	0
190-200....	7	2	.7	0

[1] Data from tables 1, 3, 4, and 5, in U. S. Dept. Agr. Tech. Bul. 630.

4 Basal area is the total cross-sectional area of trees in square feet at breast height.

Basic Concepts of Woodland Management

The concepts of management presented here are based on the thesis that the competitive status of a uniformly stocked stand is reflected by the total basal area and the number of stems per acre. When basal area is reduced by removing stems, there is an increase in the growth rate of remaining stems released from competition. Therefore, from the standpoint of management, the important point in the reduction of basal area is that at which competition is just eliminated. This would necessitate reasonable uniformity in the spacing of trees. The point in the reduction of basal area where competition is just eliminated then becomes the management control point above which the growing stand is not permitted to go. To do so would slow down the rate of growth. Growing space is provided by reducing the basal area below this control point. The objective is to give the stand just the growing space needed so the basal area would increase back to the control point by the end of the cutting cycle adapted for management.

The length of the cutting cycle should be long enough to use up the space provided adjacent trees by removing one tree (the minimum), but short enough to prevent understocking the stand unnecessarily. Thus, for a site the longer the cutting cycle the more growing space needed, and the greater understocking of the stand below the basal-area control point for preventing competition.

Nature of Management Program

The concept and method of management to obtain maximum production of usable wood products would entail initial thinning in stands 20 years of age or younger, followed with repeated periodic thinnings to maintain the fastest rate

of growth. It would tend to result in a stand or groups of trees of deep-crowned, even-aged dominants of nearly uniform diameter. Consistent with reasonably uniform spacing, the most vigorous or lowest risk trees would be left in the residual stand after each thinning. Cutting the best trees during periodic thinnings would impair the future economic production potential of the stand. Pruning also would be done to improve quality of the timber.

Spacing Requirements

In using this management concept, two things are required to determine the growing space a stand will need for any given cutting cycle: (1) The level of basal area that will eliminate competition at a specified age or size; and (2) the rate of diameter growth the stand will make. Diameter growth on the better sites will be more rapid. Therefore the growing space per tree will need to be greater on the better sites or the cutting cycle will need to be shortened. Otherwise, stands on the better sites will grow into a competitive condition first, thereby slowing down individual tree growth, and the stands on the poorer sites will have had too much space left per tree and will not fully occupy the area. Either cuts down potential production.

With these two items known, i. e., growing space required per tree and length of cutting cycle, calculations for determining the maximum number of stems that can be left to use the available growing space for a given cutting cycle can be quickly and easily made. Take, for example, a stand that has been under management and thinned. Assume that (1) the basal-area control point for eliminating competition in the stand is 160 square feet per acre, (2) the stand is now 10 inches d. b. h. and at the control point in basal area, (3) the periodic increment in diameter growth is 2 inches in 10 years, and (4) the cutting cycle is 5 years. Thus, it is known that 5 years hence the trees in this stand will be about 11 inches d. b. h. To find out how many trees of this diameter an acre will support with a basal area of 160 square feet, the 160 is divided by the factor for an area of a circle 11 inches in diameter,[5] $\frac{160}{0.6600}$ = 242 trees. The number of trees now in the stand can be determined by the same process. This calculation comes to 293 trees (160 ÷ 0.5454 for 10 inches d. b. h.). Therefore, about 51 trees should be removed from the stand. This will reduce the present basal area from 160 to 132 square feet per acre (242 x 0.5454).

One can project the average diameter of a stand to any point in the future by knowing the rate of diameter growth a stand will make without competition. Knowing the highest basal area per acre which will allow the stand to grow at that rate provides the basis for determining the maximum number of trees an acre will support at any given diameter size. All that is then required, to arrive at spacing needs and a thinning schedule, is the length of cutting cycle.

[5] Table 18, U. S. Dept. Agr. Misc. Pub. 225.

Assumed Levels of Growth From Management

Standards of Measurement

The 10-year increments in diameter and heigh growth of normal stands of ponderosa pine given in Meyers (6) are used as standards for developing thinning schedules and yield tables. Diameter-growth rates do not reflect actual diameter growth of live trees because they are also influenced by the small trees that die out of the stand. Nevertheless, they offer convenient and easily attained uniform standards. The fact that they exaggerate actual growth rates in some degree does not alter their usefulness. Actual growth increases attained can be measured in relation to these standards.

Effect of Thinning on Diameter Growth

There is general agreement among foresters that thinning in normal or overstocked young-growth stands results in increased diameter growth on the residual stems. The amount of the increase varies within limits, with the degree of thinning and the species, as well as with site, age, and degree of stocking. Research and experience to date do not indicate how much good management can increase diameter growth on given stands.

Table 3 shows, for site indexes 60, 80, and 100, the periodic diameter growth and average number of rings per radial inch for normal stands compared with what they would be if increased 50 and 100 percent by thinnings beginning at age 20 years. These increases in diameter-growth rate provide a convenient means of projecting the effects of management to show probable levels of production for analysis purposes.

Field experience by the Soil Conservation Service indicates that increases in excess of 100 percent of the normal diameter-growth rate can be realized on tree growth in young stands by thinning. Plot work exemplified by the University of Michigan's study on successive thinnings of young white pine stands indicates growth-rate increases within this range even under conditions of probable incomplete release of competition (10).

The influence of thinning on the rate of diameter growth compared to normal can be easily checked during the early years of a management program, and the actual rate projected in the same way as those in the table. This assumes, however, as does the table, that diameter growth after thinning will follow the same curve as that in normal unmanaged stands. Work by Jorgensen and Langesoe in Denmark with planted and thinned stands of Douglas-fir indicates that the diameter-growth rate of the stands actually increased with age. Data were available on these stands from age 15 to 20 years, when thinning began, until

TABLE 3.--Comparison of normal unmanaged stands of ponderosa pine with managed stands

Age class (years)	Normal unmanaged stands			Managed stands with increase in periodic growth rate of--			
				50 percent		100 percent	
	Average d. b. h.[1]	10-year growth increment	Rings per radial inch	Average d. b. h.	Rings per radial inch	Average d. b. h.	Rings per radial inch
	Inches	*Inches*	*Number*	*Inches*	*Number*	*Inches*	*Number*
20 before thinning...	1.3	--	--	--	--	--	--
20 after thinning....	--	--	--	[2] 3.0	--	[2] 3.0	--
30.....	2.3	1.0	20.0	4.5	13.3	5.0	10.0
40.....	3.2	.9	21.0	5.8	14.0	6.8	10.5
50.....	4.2	1.0	21.0	7.3	14.0	8.8	10.5
60.....	5.1	.9	21.4	8.7	14.3	10.6	10.8
70.....	6.0	.9	21.4	10.0	14.3	12.4	10.8
80.....	7.0	1.0	21.4	11.5	14.3	14.4	10.8
90.....	7.9	.9	22.2	12.9	14.8	16.2	11.1
100.....	8.8	.9	22.2	14.2	14.8	18.0	11.1
110.....	9.7	.9	22.2	15.6	14.8	19.8	11.1
120.....	10.5	.8	25.0	16.8	16.7	21.4	12.5
	SITE INDEX 80						
20 before thinning...	2.4	--	--	--	--	--	--
20 after thinning....	--	--	--	[3] 4.0	--	[3] 4.0	--
30.....	3.8	1.4	14.3	6.1	9.5	6.8	7.1
40.....	5.1	1.3	15.4	8.1	10.3	9.4	7.7
50.....	6.3	1.2	16.7	9.9	11.1	11.8	8.3
60.....	7.4	1.1	18.2	11.5	12.1	14.0	9.1
70.....	8.5	1.1	18.2	13.2	12.1	16.2	9.1
80.....	9.6	1.1	18.2	14.8	12.1	18.4	9.1
90.....	10.7	1.1	18.2	16.5	12.1	20.6	9.1
100.....	11.7	1.0	20.0	18.0	13.3	22.6	10.0
110.....	12.7	1.0	20.0	19.5	13.3	24.6	10.0
120.....	13.6	.9	22.2	20.9	14.8	26.4	11.1
	SITE INDEX 100						
20 before thinning...	3.6	--	--	--	--	--	--
20 after thinning....	--	--	--	[4] 5.0	--	[4] 5.0	--
30.....	5.5	1.9	10.5	7.8	7.1	8.8	5.3
40.....	7.0	1.5	13.3	10.0	9.1	11.8	6.7
50.....	8.5	1.5	13.3	12.2	9.1	14.8	6.7
60.....	9.7	1.2	16.7	14.0	11.1	17.2	8.3
70.....	10.9	1.2	16.7	15.8	11.1	19.6	8.3
80.....	12.1	1.2	16.7	17.6	11.1	22.0	8.3
90.....	13.3	1.2	16.7	19.4	11.1	24.4	8.3
100.....	14.5	1.2	16.7	21.2	11.1	26.8	8.3
110.....	15.6	1.1	18.2	22.8	12.5	29.0	9.1
120.....	16.6	1.0	20.0	24.3	13.3	31.0	10.0

[1] U. S. Dept. Agr. Tech. Bul. 630, table 5, p. 14.

[2] U. S. Dept. Agr. Tech Bul. 630, table 28, p. 37. Estimate based on between 237 and 268 of the largest trees.

[3] U. S. Dept. Agr. Tech. Bul. 630, table 28, p. 37. Estimate based on between 270 and 300 of the largest trees.

[4] U. S. Dept. Agr. Tech. Bul. 630, table 28, p. 37. Estimate based on between 269 and 363 of the largest trees.

TOP, A stagnated stand of young ponderosa pine on site indexes 70 to 80. BOTTOM, Precommercially thinned at an age when maximum tree growth can be obtained.

age 37. In comparison to this Danish experience, the assumptions used in table 3 are conservative.

Further work may prove that with proper management the diameter-growth rate can be maintained or increased with age during the early years of a stand. In other words, it may be possible to alter the shape of the normal growth curve during the period most vital to the economic success of management.

Table 4 indicates a thinning schedule for site indexes 60, 80, and 100 in ponderosa pine based on a 100-percent increase in the periodic diameter growth in normal fully stocked stands.

in basal area lost through mortality in stands of widely different sites, and (2) the amount of basal area lost decreases with age after the stand has reached maximum basal area for the site.

The fact that basal area remains relatively constant indicates that mortality is a measure of the competitive tolerance of the species, a factor inherent with the plant. This inherent factor is not appreciably influenced by site. In other words, the amount of reduction in basal area to eliminate competition in a normal stand is about the same for all sites.

The assumptions represent reductions equivalent to the approximate highest basal area lost in

TABLE 4.--Calculated thinning schedules per acre for managed[1] stands of ponderosa pine, based on 100-percent increase in the diameter-growth rate of normal stands[2]

Age class (years)	Index 60				Index 80				Index 100			
	Average diameter	Trees removed	Trees remaining	Basal-area remaining	Average diameter	Trees removed	Trees remaining	Basal-area remaining	Average diameter	Trees removed	Trees remaining	Basal-area remaining
	Inches	*Number*	*Number*	*Square feet*	*Inches*	*Number*	*Number*	*Square feet*	*Inches*	*Number*	*Number*	*Square feet*
35.....	--	--	--	--	--	--	--	--	10.3	78	250	145
40.....	--	--	--	--	--	--	--	--	11.8	53	197	150
45.....	--	--	--	--	10.6	50	210	129	13.3	38	159	153
50.....	--	--	--	--	11.8	34	176	134	14.8	23	136	162
55.....	--	--	--	--	12.9	26	150	136	16.0	18	118	165
60.....	10.6	32	180	110	14.0	21	129	138	17.2	15	103	166
65.....	11.5	25	155	112	15.1	17	112	139	18.4	12	91	168
70.....	12.4	22	133	112	16.2	14	98	140	19.6	11	80	168
75.....	13.4	18	115	113	17.3	11	87	142	20.8	8	72	170
80.....	14.4	13	102	115	18.4	10	77	142	22.0	7	65	172
85.....	15.3	11	91	116	19.5	8	69	143	23.2	6	59	173
90.....	16.2	9	82	117	20.6	7	62	144	24.4	6	53	172
95.....	17.1	7	74	118	21.6	6	57	145	25.6	4	49	175
100.....	18.0	7	67	118	22.6	4	53	148	26.8	4	45	176
105.....	18.9	6	61	119	23.6	4	49	149	27.9	4	41	174
110.....	19.8	5	56	120	24.6	4	45	149	29.0	3	38	174
115.....	20.6	4	52	120	25.5	3	42	149	30.0	2	36	178
120[3]....	21.4	52	--	--	26.4	42	--	--	31.0	36	--	--

[1] Management program of stand improvement started at age 20 years.
[2] U. S. Dept. Agr. Tech. Bul. 630.
[3] Residual stand carried only until age 120 years in these calculations.

In calculating these schedules, it was assumed that the management control point for site indexes 60, 80, and 100 is 130, 160, and 190 square feet of basal area per acre, respectively. These assumptions were arrived at after considering the basal area lost through mortality in normal fully stocked stands for different periods. Although calculations of this basal area, based on data from Meyers (6), must be rough, nevertheless they indicate two things: (1) That over a period of years there is little difference

mortality during a 20-year period. The time factor between thinnings in table 4 is 5 years. The accuracy of these assumptions must await the test of further experience and research.

If competition in a stand is the function of the plant and the competitive tolerance of a species is known, competition can be eliminated as a variable in determining growing space. The rate at which a tree grows is determined by its environment--the physical characteristics of

the site. With competition in the stand eliminated as a variable, trees grow faster on good sites than on poor sites. Therefore, to provide sufficient growing space for a given period of time (5 years in these schedules), more space per acre in terms of basal area must be provided for the better sites than for the poorer ones. That is, on the better sites it is necessary to understock to a greater degree below the point where competition is just eliminated in the stand than it is on the poorer sites.

Because diameter growth is the primary determinant of spacing requirements of trees by sites, age automatically becomes a factor. In comparing the thinning schedules in table 4, as well as Meyers' (6) normal stands, by sites, the poorer the site, the greater is the number of stems per acre at a given age. Poorer sites support more stems per acre at comparable age classes with a lower basal area because the rate of growth is slower. This is directly and basically related to the growth-producing potential inherent in the site. The poorer sites have lower basal areas and therefore cannot support as many stems per acre at the same diameter as can the better sites. The difference comes in the age at which a certain diameter is attained on different sites. This is illustrated by the following comparison of per-acre data summarized from table 4.

Site index	Age class	Diameter d. b. h.	Trees removed	Trees after thinning	Basal area of residual stand	Space per tree
	Years	*Inches*	*Number*	*Number*	*Square feet*	*Square feet*
100	60	17.2	15	103	166	423
80	60	14.0	21	129	138	338
60	60	10.6	32	180	110	242
100	55	16.0	18	118	165	369
80	70	16.2	14	98	140	444
60	90	16.2	9	82	117	531

Relationship of Basal Area of Residual Stand to Age

Also (table 4) basal area of the residual stand tends to increase with age of the stand. This indicates that a thinning program in ponderosa pine aimed at reducing basal area per acre to a constant amount at each thinning is not a sound basis for management. It either (1) would be cutting into the residual stand unduly and thereby not fully utilizing all the available growing space as the stand grew older, or (2) would be leaving the stand in competition throughout much of the cutting cycle. This relationship is substantiated by the fact that basal area of mortality in normal fully stocked stands also decreases with age of the stand.

Effect of Management on Height Growth

It is generally concluded by Hawley and Smith (5), Spurr (9), and others that within fairly wide ranges of density there is little difference in height growth on a given site. Exceptions to this have been reported by Steele (8) in young Douglas-fir stands and by Mowats (7) in ponderosa pine. It therefore appears that additional work is needed before definite conclusions can be drawn on this subject, particularly as it relates to conifers. If, through proper management of young stands, the rate of height growth can be increased for a time, it would have significant economic implications.

Calculations are given here to indicate levels of production with no increase in the normal rate of height growth and with a 10-percent increase.

Influence of Management on Tree-Form Factor

The form factor--the degree of taper in the bole or stem of the tree--could materially influence the board-foot volume produced. Trees that have a high degree of taper (low form factor) contain less board-foot volume for a given height and d. b. h. than do trees that are more cylindrical or less tapered. Open grown trees tend to taper more than do trees grown in normal stands.

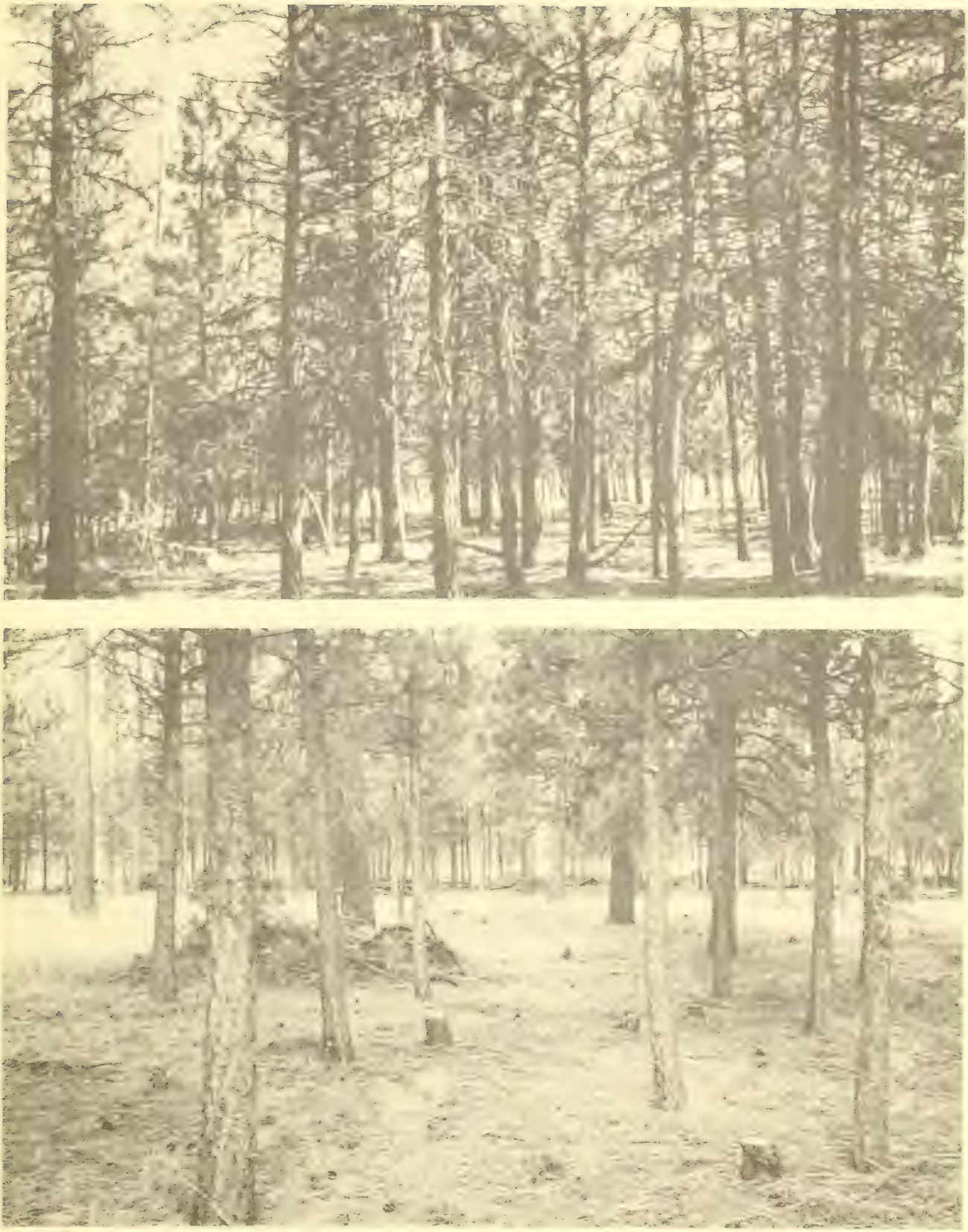
Does opening the stand by thinning have any effect on the form factor of pruned trees? Spurr (9) states: "Variation in stand form is sufficiently related to basal area and height that it may apparently be safely ignored if these two variables are included." In citing the work of others, he concludes: "Changes in form following release are not large, and may be ignored in most volume and growth estimation."

Accordingly, the tree-form factor has not been considered in calculating expected volume yields in this report.

Calculated Future Yields

Tables 5, 6, and 7 show calculated yields in board-foot volume for site indexes 60, 80, and 100, based on the previously stated assumptions as to basal area and rates of diameter increase of 50 and 100 percent and rates of height increases of 0 and 10 percent, calculated to 120 years of age.

Total board-foot volume production varies, depending on the rates of diameter and height growth used. Most significant from the standpoint of management is that the difference in volume is more pronounced at earlier ages. For example, for site index 80 with 100-percent increase in diameter-growth rate and 10-percent increase in height-growth rate at age 60, the board-foot volume produced totals 16,790



TOP, A normal-stocked stand of 50-year-old ponderosa pine, site index 80. BOTTOM, The same stand thinned and pruned. Some saw logs were removed in this first thinning; however, these practices were applied too late to obtain maximum benefits.

TABLE 5.--Calculated thinning schedule and board-foot volume production per acre of managed stands of ponderosa pine, site index 60

50-PERCENT INCREASE IN DIAMETER-GROWTH RATE[1]

Age class (years)	Average diameter[2]	Trees removed	Trees remaining	Basal area remaining	No increase in height growth rate			10-percent increase in height growth rate		
					Average height	Volume[3] removed	Volume[3] remaining	Average height[2]	Volume[3] removed	Volume[3] remaining
	Inches	*Number*	*Number*	*Square feet*	*Feet*	*Board-feet*	*Board-feet*	*Feet*	*Board-feet*	*Board-feet*
70.....	10.0	66	204	111	47	660	2,040	51	725	2,245
75.....	10.8	24	180	114	50	530	3,960	54	625	4,680
80.....	11.5	20	160	115	52	690	5,520	56	770	6,160
85.....	12.2	17	143	116	55	800	6,790	59	880	7,420
90.....	12.9	14	129	117	57	815	7,510	61	915	8,435
95.....	13.6	12	118	119	59	865	8,520	63	980	9,650
100.....	14.2	11	107	118	60	925	8,990	64	1,060	10,315
105.....	14.9	9	98	118	62	940	10,280	66	1,070	11,635
110.....	15.6	7	91	121	63	865	11,230	68	995	12,960
115.....	16.2	7	84	120	65	1,015	12,180	70	1,155	13,860
120.....	16.8	84	0	0	66	13,440	0	71	15,320	0
Total board-foot volume produced						21,545			24,495	
Board-foot volume of normal unmanaged stand at 120 years						12,500				

100-PERCENT INCREASE IN DIAMETER-GROWTH RATE[4]

60.....	10.6	32	180	110	42	455	2,555	45	510	2,880
65.....	11.5	25	155	112	45	625	3,875	48	740	4,575
70.....	12.4	22	133	112	47	835	5,055	51	995	6,010
75.....	13.4	18	115	113	50	970	6,210	54	1,095	6,990
80.....	14.4	13	102	115	52	935	7,345	56	1,040	8,160
85.....	15.3	11	91	116	55	1,055	8,735	59	1,145	9,465
90.....	16.2	9	82	117	57	1,055	9,610	61	1,160	10,580
95.....	17.1	7	74	118	59	1,010	10,685	63	1,115	11,805
100.....	18.0	7	67	118	60	1,190	11,390	64	1,300	12,460
105.....	18.9	6	61	119	62	1,200	12,285	66	1,315	13,370
110.....	19.8	5	56	120	63	1,150	12,865	68	1,270	14,235
115.....	20.6	4	52	120	65	1,050	13,675	70	1,165	15,130
120.....	21.4	52	0	0	66	15,255	0	71	16,920	0
Total board-foot volume produced						26,785			29,770	
Board-foot volume of normal unmanaged stand of 120 years						12,500				

[1] Thinned at age 20 years to 300 trees and pruned to height of 4 feet. Tree mortality from age 20 to 70 years calculated at 30 trees. Basal area of 130 square feet used as control in calculating thinning schedule and residual stand. Basal area was cut below 130 square feet every 5 years to provide sufficient growing space in residual stand so that it would not exceed 130 square feet by the time of the next thinning.

[2] Based on percentage increases in normal periodic growth rate as shown in U. S. D. A. Tech. Bul. 630.

[3] Scribner rule.

[4] Thinned at age 20 years to 237 trees and pruned to height of 4 feet. Pruned at age 40 years to 10 feet. Tree mortality from age 20 to 60 years calculated at 25 trees. Basal area of 130 square feet used as control in calculating thinning schedule and residual stand. Basal area was cut below 130 square feet every 5 years to provide sufficient growing space in residual stand so that it would not exceed 130 square feet by the time of the next thinning.

TABLE 6.--Calculated thinning schedule and board-foot volume production per acre of managed stands of ponderosa pine, site index 80

50-PERCENT INCREASE IN DIAMETER-GROWTH RATE[1]

Age class (years)	Average diameter[2]	Trees removed	Trees remaining	Basal area remaining	No increase in height growth rate			10 percent increase in height growth rate		
					Average height	Volume[3] removed	Volume[3] remaining	Average height[2]	Volume[3] removed	Volume[3] remaining
	Inches	*Number*	*Number*	*Square feet*	*Feet*	*Board-feet*	*Board-feet*	*Feet*	*Board-feet*	*Board-feet*
50.....	9.9	31	256	137	51	310	2,560	54	400	3,330
55.....	10.7	34	222	138	55	865	5,660	58	970	6,325
60.....	11.5	31	191	138	58	1,255	7,735	62	1,365	8,405
65.....	12.4	23	168	141	61	1,320	9,645	66	1,480	10,820
70.....	13.2	18	150	143	64	1,380	11,520	69	1,585	13,200
75.....	14.0	16	134	143	67	1,615	13,535	72	1,825	15,275
80.....	14.8	15	119	142	70	1,950	15,470	75	2,100	16,660
85.....	15.7	11	108	145	73	1,745	17,120	78	1,855	18,200
90.....	16.5	10	98	146	75	1,835	18,000	81	1,985	19,455
95.....	17.3	8	90	147	78	1,700	19,145	84	1,890	21,260
100....	18.0	7	83	147	80	1,680	19,920	86	1,890	22,410
105....	18.8	6	77	148	82	1,690	21,715	88	1,870	24,025
110....	19.5	5	72	149	84	1,600	23,040	90	1,750	25,200
115....	20.2	5	67	149	86	1,800	24,090	93	2,005	26,865
120....	20.9	67	0	0	88	27,075	0	95	30,150	0
Total board-foot volume produced						47,820			53,120	
Board-foot volume of normal unmanaged stand at 120 years						26,200				

100-PERCENT INCREASE IN DIAMETER-GROWTH RATE[4]

45.....	10.6	50	210	129	47	860	3,610	49	920	3,865
50.....	11.8	34	176	134	51	1,290	6,690	54	1,395	7,215
55.....	12.9	26	150	136	55	1,460	8,430	58	1,575	9,090
60.....	14.0	21	129	138	58	1,595	9,805	62	1,805	11,095
65.....	15.1	17	112	139	61	1,795	11,815	66	2,095	13,810
70.....	16.2	14	98	140	64	1,975	13,820	69	2,255	15,780
75.....	17.3	11	87	142	67	1,985	15,705	72	2,175	17,210
80.....	18.4	10	77	142	70	2,220	17,095	75	2,390	18,405
85.....	19.5	8	69	143	73	2,150	18,525	78	2,330	20,080
90.....	20.6	7	62	144	75	2,235	19,780	81	2,465	21,840
95.....	21.6	6	57	145	78	2,270	21,590	84	2,490	23,665
100....	22.6	4	53	148	80	1,750	23,160	86	1,905	25,260
105....	23.6	4	49	149	82	1,990	24,360	88	2,170	26,595
110....	24.6	4	45	149	84	2,250	25,345	90	2,450	27,585
115....	25.5	3	42	149	86	1,880	26,355	93	2,075	29,020
120....	26.4	42	0	0	88	29,265	0	95	32,255	0
Total board-foot volume produced						56,970			62,750	
Board-foot volume of normal unmanaged stand at 120 years						26,200				

[1] Thinned at age 20 years to 302 trees and pruned to height of 6 feet. Pruned at age 30 years to 12 feet. Pruned at age 40 years to 18 feet. Tree mortality from age 20 to 50 years calculated at 15 trees. Basal area of 160 square feet used as control in calculating thinning schedule and residual stand. Basal area was cut below 160 square feet every 5 years to provide sufficient growing space in residual stand so that it would not exceed 160 square feet by the time of the next thinning.

[2] Based on percentage increases in normal periodic growth rate as shown in U. S. D. A. Tech. Bul. 630.

[3] Scribner rule.

[4] Thinned at age 20 years to 275 trees and pruned to height of 6 feet. Pruned at age 30 years to 12 feet. Pruned at age 40 years to 18 feet. Tree mortality from age 20 to 45 years calculated at 15 trees. Basal area of 160 square feet used as control in calculating thinning schedule and residual stand. Basal area was cut below 160 square feet every 5 years to provide sufficient growing space in residual stand so that it would not exceed 160 square feet by the time of the next thinning.

TABLE 7.--Calculated thinning schedule and board-foot volume production per acre of managed stands of ponderosa pine, site index 100

50-PERCENT INCREASE IN DIAMETER-GROWTH RATE[1]

Age class (years)	Average diameter[2]	Trees removed	Trees remaining	Basal area remaining	No increase in height growth rate			10 percent increase in height growth rate		
					Average height	Volume[3] removed	Volume[3] remaining	Average height[2]	Volume[3] removed	Volume[3] remaining
	Inches	*Number*	*Number*	*Square feet*	*Feet*	*Board-feet*	*Board-feet*	*Feet*	*Board-feet*	*Board-feet*
40.....	10.0	65	283	154	55	975	4,245	57	1,105	4,810
45.....	11.1	49	234	157	60	1,790	8,540	63	1,885	9,010
50.....	12.2	31	203	165	65	1,830	11,975	68	1,940	12,710
55.....	13.1	25	178	167	69	2,135	15,200	73	2,340	16,645
60.....	14.0	21	157	168	73	2,435	18,210	77	2,605	19,470
65.....	14.9	17	140	170	77	2,490	20,510	81	2,635	21,700
70.....	15.8	15	125	170	80	2,625	21,875	85	2,840	23,690
75.....	16.7	13	112	170	84	2,805	24,170	90	3,095	26,665
80.....	17.6	10	102	172	88	2,650	27,010	94	2,925	29,825
85.....	18.5	9	93	174	91	2,840	29,340	97	3,135	32,410
90.....	19.4	8	85	174	94	2,970	31,585	100	3,280	34,850
95.....	20.3	7	78	175	97	3,040	33,850	104	3,305	36,830
100....	21.2	6	72	176	100	3,000	36,000	107	3,220	38,620
105....	22.0	5	67	177	103	2,790	37,385	110	3,000	40,200
110....	22.8	4	63	179	106	2,515	39,615	113	2,720	42,800
115....	23.6	4	59	179	109	2,820	41,560	116	3,055	45,050
120....	24.3	59	0	0	111	45,615	0	118	49,395	0
Total board-foot volume produced						85,325			92,480	
Board-foot volume of normal unmanaged stand at 120 years						44,600				

100-PERCENT INCREASE IN DIAMETER-GROWTH RATE[4]

35.....	10.3	78	250	145	49	1,110	3,550	51	1,210	3,875
40.....	11.8	53	197	150	55	2,225	8,275	57	2,330	8,670
45.....	13.3	38	159	153	60	2,640	11,050	63	2,905	12,150
50.....	14.8	23	136	162	65	2,600	15,370	68	2,835	16,755
55.....	16.0	18	118	165	69	2,810	18,410	73	2,990	19,590
60.....	17.2	15	103	166	73	2,970	20,395	77	3,125	21,445
65.....	18.4	12	91	168	77	2,950	22,370	81	3,130	23,750
70.....	19.6	11	80	168	80	3,345	24,320	85	3,620	26,320
75.....	20.8	8	72	170	84	2,970	26,725	90	3,280	29,520
80.....	22.0	7	65	172	88	3,200	29,770	94	3,485	32,370
85.....	23.2	6	59	173	91	3,260	32,070	97	3,535	34,765
90.....	24.4	6	53	172	94	3,815	33,685	100	4,115	36,360
95.....	25.6	4	49	175	97	2,940	36,025	104	3,220	39,475
100....	26.8	4	45	176	100	3,400	38,250	107	3,720	41,840
105....	27.9	4	41	174	103	3,865	39,625	110	4,210	43,130
110....	29.0	3	38	174	106	3,270	41,420	113	3,525	44,630
115....	30.0	2	36	178	109	2,415	43,450	116	2,585	46,510
120....	31.0	36	0	0	111	47,250	0	118	50,400	0
Total board-foot volume produced						97,035			104,220	
Board-foot volume of normal unmanaged stand at 120 years						44,600				

[1] Thinned at age 20 years to 363 trees and pruned to height of 9 feet. Pruned at age 30 years to 18 feet. Tree mortality from age 20 to 40 years calculated at 15 trees. Basal area of 190 square feet used as control in calculating thinning schedule and residual stand. Basal area was cut below 190 square feet every 5 years to provide sufficient growing space in residual stand so that it would not exceed 190 square feet by the time of the next thinning.

[2] Based on percentage increases in normal periodic growth rate as shown in U. S. D. A. Tech. Bul. 630.

[3] Scribner rule.

[4] Thinned at age 20 years to 338 trees and pruned to height of 9 feet. Pruned at age 30 years to 18 feet. Tree mortality from age 20 to 35 years calculated at 10 trees. Basal area of 190 square feet used as control in calculating thinning schedule and residual stand. Basal area was cut below 190 square feet every 5 years to provide sufficient growing space in residual stand so that it would not exceed 190 square feet by the time of the next thinning.

board feet compared to 5,100 board feet in a normal stand at that age. The difference at this age is 3.3 times greater in the managed stand. At 80 years of age the difference is 2.7 times greater, and at 120 years, 2.4 times greater.

These calculated yields are based on maintaining 100-percent stocking throughout the rotation. It is recognized that this degree of stocking is almost impossible to maintain, so that these yields represent optimum rather than attainable production at the specified growth rates.

Effect of Delayed Thinning on Future Yields

The older the age class on which a management program of thinning and pruning is started, the less the increase in usable production that can be expected. Increased diameter growth and possibly increased height growth result from larger manufacturing plants, i. e., deeper and wider crowns with the attendant greater root systems that develop on the selected trees under management. As a normal stand develops without management, the live crowns on the dominants and co-dominants are forced higher and higher on the stem by the extreme competition that exists between trees of all crown classes. Thus, the longer management is delayed in the age of a normal second-growth stand of conifers, the smaller the relative size of the manufacturing plant per tree available to produce growth when released. This difference in the size and shape of crowns on Douglas-fir with and without thinning was well illustrated by Brieglieb (2).

A normal stand released at an older age can never catch up in total volume of usable wood products with that produced by similar stands released at an earlier age. Not only would there be failure to take advantage, by management, of the faster growth during the earlier age of the stand, but the normal mortality that occurred in the meantime can never be salvaged.

Hawley and Smith (5) also point out that the older the stand at the time of initial release, the more susceptible it becomes to windthrow, disease, insects, and physiological disorders which attack trees weakened by competition. They sum up this situation by stating: "In most stands, failure to thin should be looked upon as a lost opportunity. . . . ." The longer thinning is put off, the greater the opportunity lost.

Application and Significance of Management Concepts

The foregoing concepts and basic principles of woodland growth and management are believed applicable to all conifers that tend to grow in even-aged stands.

The method presented here for determining growing space requirements and predicting future yields under management as a means to economic evaluation are believed applicable primarily to conifers having the growth and environmental characteristics of ponderosa pine.

The level of management is based on the maximum growth that release of competition permits. This is believed important because time is by far the biggest cost factor in woodland management. Many foresters disagree with this level of management on the ground that it imposes a thinning program that is too severe. They prefer the quality of timber produced under some competition within the stand as a result of more stems per acre. Even so, the method presented here can be used by raising the basal-area control point on which thinning is based and taking a reduced rate of growth per stem.

This method in no way conflicts with good management practices necessary for regeneration. It deals with the stand during its precommercial thinning, commercial thinning, and intermediate harvest stages of development. It takes the stand to economic maturity--readies it for the final harvest or regeneration cut.

Applicability to Understocked Stands

These management concepts can apply to understocked stands in the same way as they would to fully stocked stands after one or more thinnings. If percent of stocking, average diameter size, and rate of growth of a stand are known, the number of stems and needed growing space can be calculated and fitted into a thinning schedule.

Understocking to a point, assuming reasonable distribution of stems and barring serious competition from other vegetation, is in effect the same as thinning and should react on growth the same way. Until the stands grows back into normality (a competitive stand) there should be accelerated growth and greater production per stem than that in normal fully stocked stands of the same age and site.

In such understocked stands initial thinning may be delayed until the stand has reached a point of competition without loss in rate of growth. Pruning likely will be required, though, to improve quality. Actually, these stands have a distinct economic advantage over normal fully stocked stands that need precommercial thinning.

It is common for ponderosa pine to grow in clumps with open spaces between. A given acre of land may be understocked because of this, but overstocked within the clumps. Such clumps would, of course, need thinning. Stocking, as used in this report, is based on an acre fully stocked with trees and not on a given acre of land.

Spacing in Initial Thinning

As a matter of economics, the growing space provided in the initial thinning of a 15- to 20-year old fully stocked stand usually should be

greater than that required to obtain maximum production. Maximum production is pointless unless a merchantable product is being produced that justifies harvest. Thus, from an economic standpoint, spacing in the initial thinning should be sufficient to permit harvesting a commercial product at the time of the second thinning.

The primary objective of management is to obtain the greatest growth of highest commercial value in the shortest possible time. As Craib (3)[6] found out in his work in South Africa, total wood increment is unimportant unless that increment has commercial value.

However ever-changing technology and wood-fiber demands will have an important bearing on future commercial values. Today, ponderosa pine is largely on a sawlog economy. Tomorrow, the situation may be quite different.

Processes are being developed now for using this species as pulpwood. Stud mills are also coming into use which utilize logs of a much smaller diameter than was once thought profitable. In other important species, such as Douglas-fir, markets are already well established to utilize thinnings of fairly small diameter.

The yield tables presented here are based on sawlogs from trees 10 to 11 inches d. b. h., as the initial commercial product. This is probably conservative with respect to future markets for this species.

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